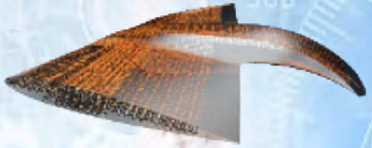
National Aeronautics and Space Administration

ARMD Transformative Aeronautics Concepts Program

CONVERGENT AERONAUTICS SOLUTIONS



MADCAT

Mission Adaptive Digital Composite Aerostructure Technologies

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NASA Ames Research Center

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Contents

MADCAT

- Lead Center & Partner Centers: ARC, LaRC
- External Collaborators: MIT, University of Alabama, Michigan State University, UC Santa Cruz, Moog Inc.
- Big Question: *Can We Merge Revolutionary Concepts in Materials and Manufacturing with Long Standing Aeronautics Challenges for the Next Generation of Air Vehicles?*
- ARMD Strategic Thrusts and associated Outcome(s) addressed:
    - Strategic Thrust 3: Ultra-Efficient Commercial Vehicles
    - Subsonic Transport Outcome (> 2035): Technology and Configuration Concept[s] […] that Stretch Beyond N+3 Levels of Efficiency and Environmental Performance.
- Idea/Concept: A novel aerostructure concept that takes advantage of emerging digital composite materials and manufacturing methods to build high stiffness-to-density ratio, ultra-light structures that can provide mission adaptive and aerodynamically efficient future N+3/N+4 air vehicles.
- Feasibility Assessment: Prove that the proposed novel digital aerostructure concept can significantly impact mission performance through integration in multidisciplinary flight systems.
- Feasibility Assessment Criteria: a) Build a scaled UAV prototype; b) Demonstrate weight benefit and efficient production process; c) Demonstrate mission adaptive flight performance; d) Demonstrate design concept scalability.
- Duration of Execution: 2 years

Impact, Progress and Risk

Impact:

Cost effective digital manufacturing strategy for high performance applications; integrated lattice-based structure and flight controls for mission adaptive flight planning to increase aerodynamic performance; scalability of the digital fabrication and construction concept to commercial transport aircraft. Dr. Gonzalo Rey, Director of Research and Technology at Moog Inc. (Buffalo, NY), indicated that the MADCAT project ***"is one of the few technologies that has the potential to truly reinvent major aspects of how our industry does its job,"*** and has been actively collaborating with MADCAT team.

Progress:

- During CAS Incubation Study: An all-composite prototype scaled UAV (MADCAT v0) build initiated; relevant hardware and component mechanisms designed and fabricated.
- 1st year CAS Execution: Validated calibration bench tests for MADCAT v0; successful MADCAT v0 preliminary flight tests; demonstrated aeroelastic and large volume digital aerostructure modeling capability; demonstrated (analytically) the scalability of digital components and discrete construction concept.

Risk:

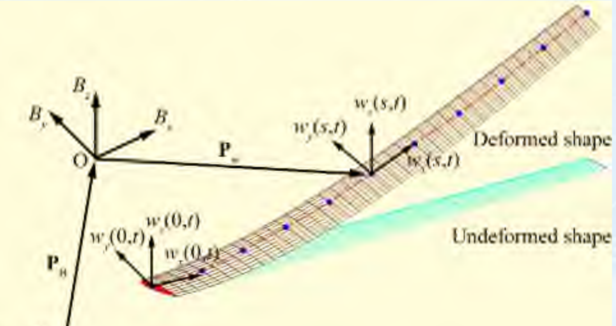
- Programmatic: a) Flight worthiness and safety review process for low cost and high risk unmanned flight technology demonstrator, such as MADCAT, should follow a more concise review process; b) Each modification to airframe and/or flight hardware requires a delta review that can be more resource intensive than building a new aircraft.
- Technical: a) Modeling and analysis of large heterogeneous (multiple part types) aerostructures still present interesting challenges; b) Full vehicle-level performance assessment may be complex.
- Implementation: a) The project outcomes contribute directly to the Performance Adaptive Aeroelastic Wing study under ARMD Advanced Air Transport Technology project and the Earth sciences projects; b) Ultra-light structure and discrete construction strategy based on digital composite technology is another potential transition technology.

Status Report: Demonstrate Rapid Aeroelastic Modeling Capability

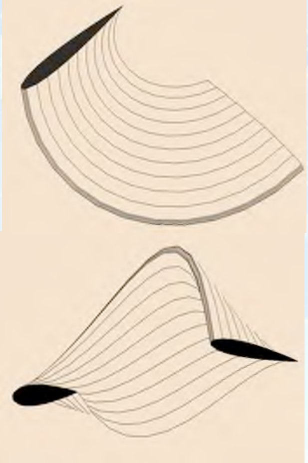
- Aeroelastic equations of motion

$$M(\varepsilon)\begin{Bmatrix}\ddot{\varepsilon}\\ \dot{\beta}\end{Bmatrix}+C(\varepsilon,\dot{\varepsilon},\beta)\begin{Bmatrix}\dot{\varepsilon}\\ \beta\end{Bmatrix}+K\begin{Bmatrix}\varepsilon\\ b\end{Bmatrix}=R(\varepsilon,\dot{\varepsilon},\ddot{\varepsilon},\zeta,\beta,\dot{\beta},\lambda,u)$$

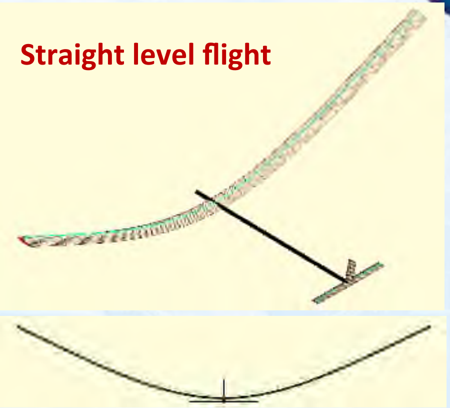
$$\dot{\lambda}=F_1\begin{Bmatrix}\ddot{\varepsilon}\\ \dot{\beta}\end{Bmatrix}+F_2\begin{Bmatrix}\dot{\varepsilon}\\ \beta\end{Bmatrix}+F_3\lambda$$

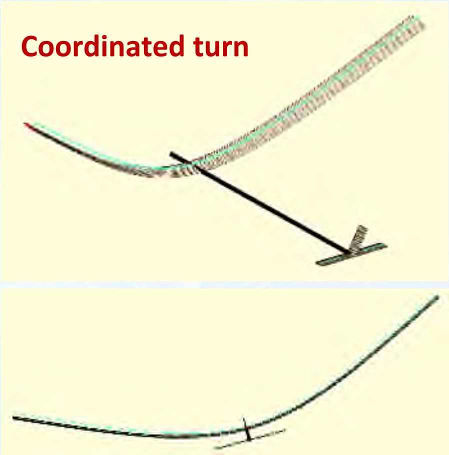


Strains (ε) and body velocities (β) are independent variables



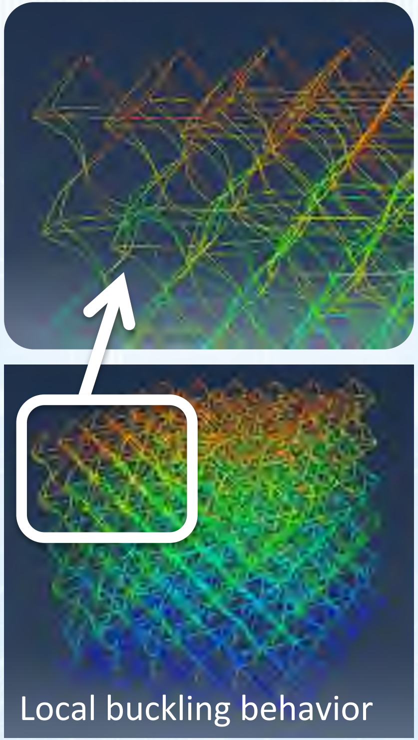
Sample element deformations with constant strain

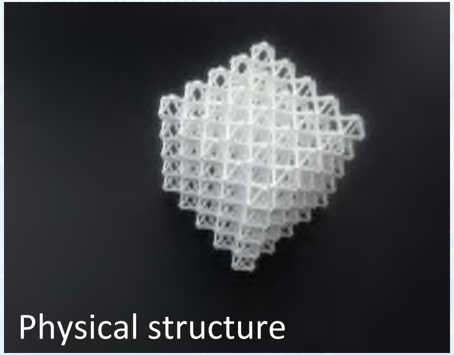


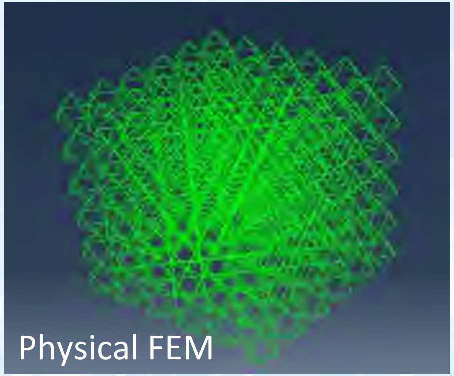


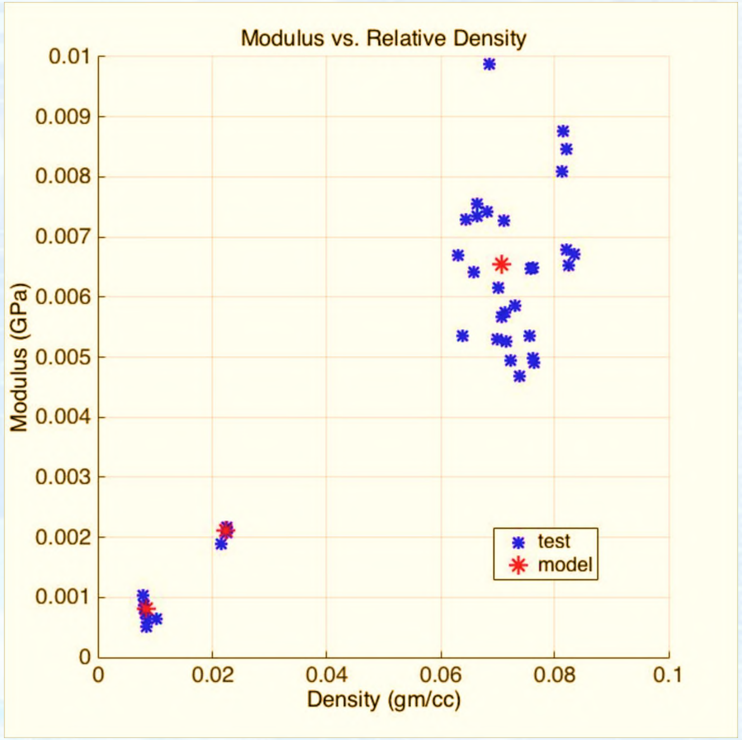
Modal-based optimization scheme for finding the Optimum Wing Geometry has ***proven to be feasible***![1]

Status Report: Demonstrate Physical Finite Element (PFE) Based Modeling Capability



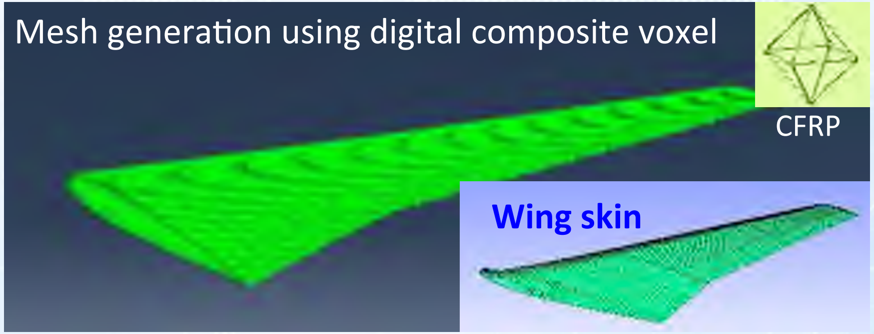






High fidelity Physical Finite-Element (PFE) modeling for digital aerostructures is ***proven to be feasible!***

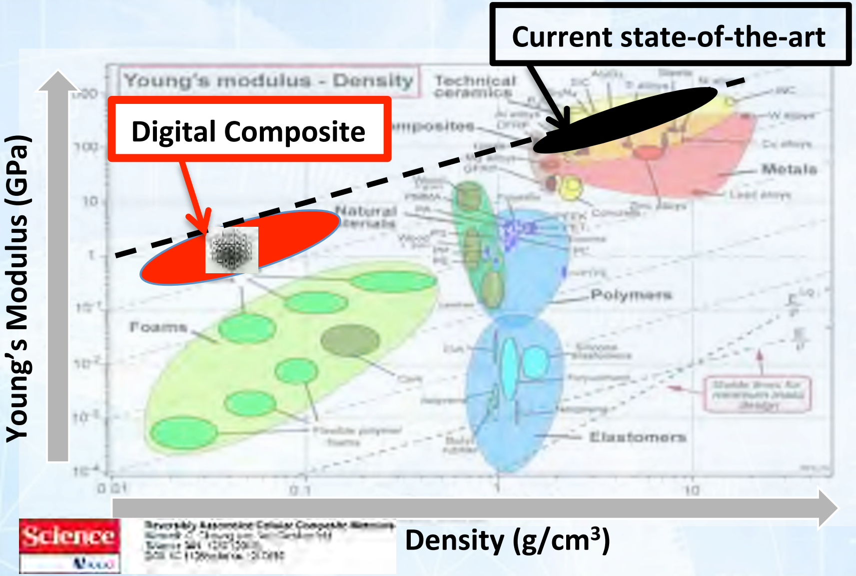
Status Report: Demonstrate Scalability of Digital Composite and Discrete Construction Concept



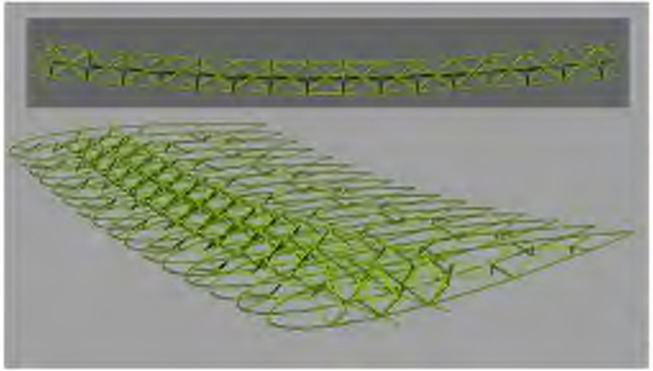
Scalability of digital composite aerostructure concept is ***proven to be feasible!***

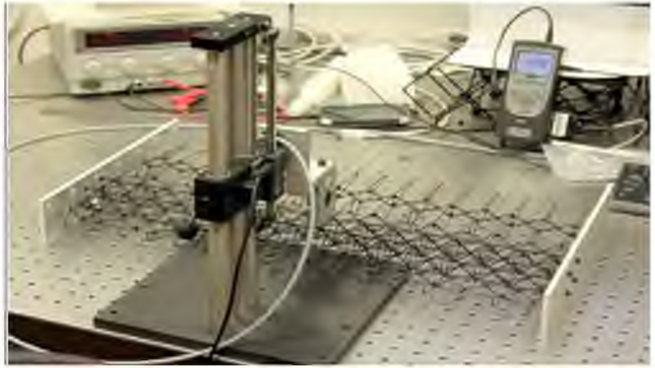
Edge cross section

	1st B (Hz)	2nd B (Hz)	1st T (Hz)	B Stiff (lbf/in)	Weight (lbf)
Reference	1.37	4.15	8.1	400	13,500
0.052”	1.99	7.60	13.82	132	1,708
0.104”	2.21	8.07	15.75	140	2,326
0.25”	1.70	6.31	12.53	185	5,798
0.5”	1.27	4.72	9.67	338	14,686



Status Report: MADCAT v0 Calibration Bench Tests

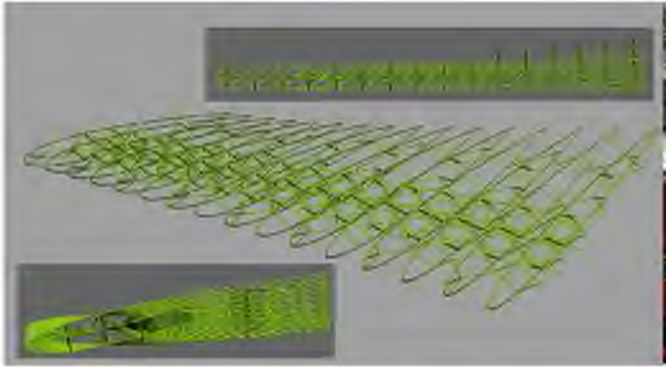




Three-point bending tests

Experimental: **191 MPa**

Simulations: **184 MPa**



Torsional loading tests

Experimental: **12 Nm/rad**

Simulations: **14.9 Nm/rad**

Developed a modeling capability that can predict aerostructure properties with accuracy

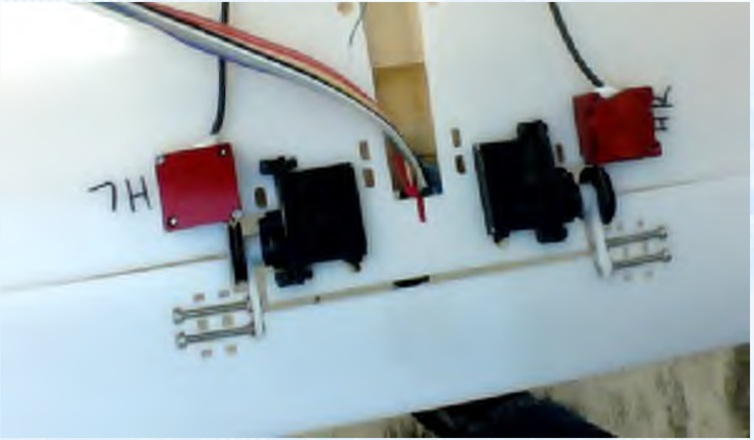
Status Report: MADCAT v0 Preliminary Flight Tests

Flight boundary
Flight crew
Vehicle staging area

Demonstrated flight worthiness through flight tests

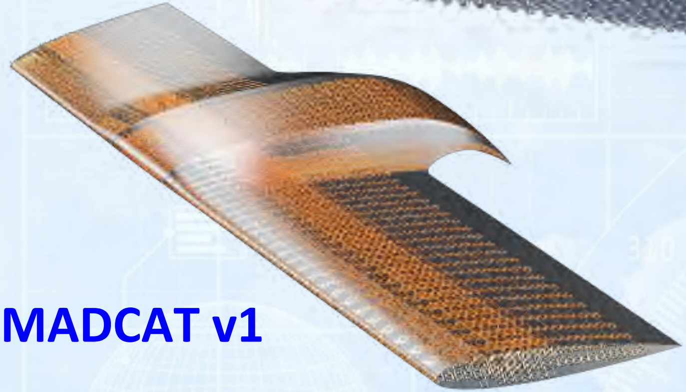
Status Report: MADCAT v0 Preliminary Flight Tests

Next Steps: Instrumented Flight Tests

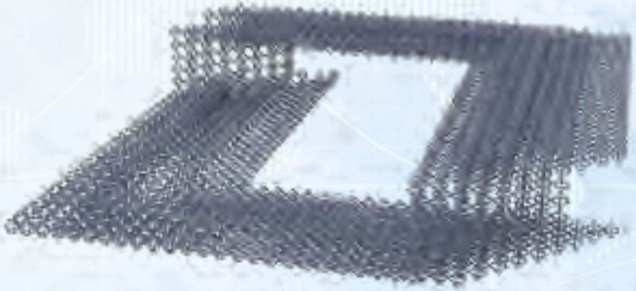


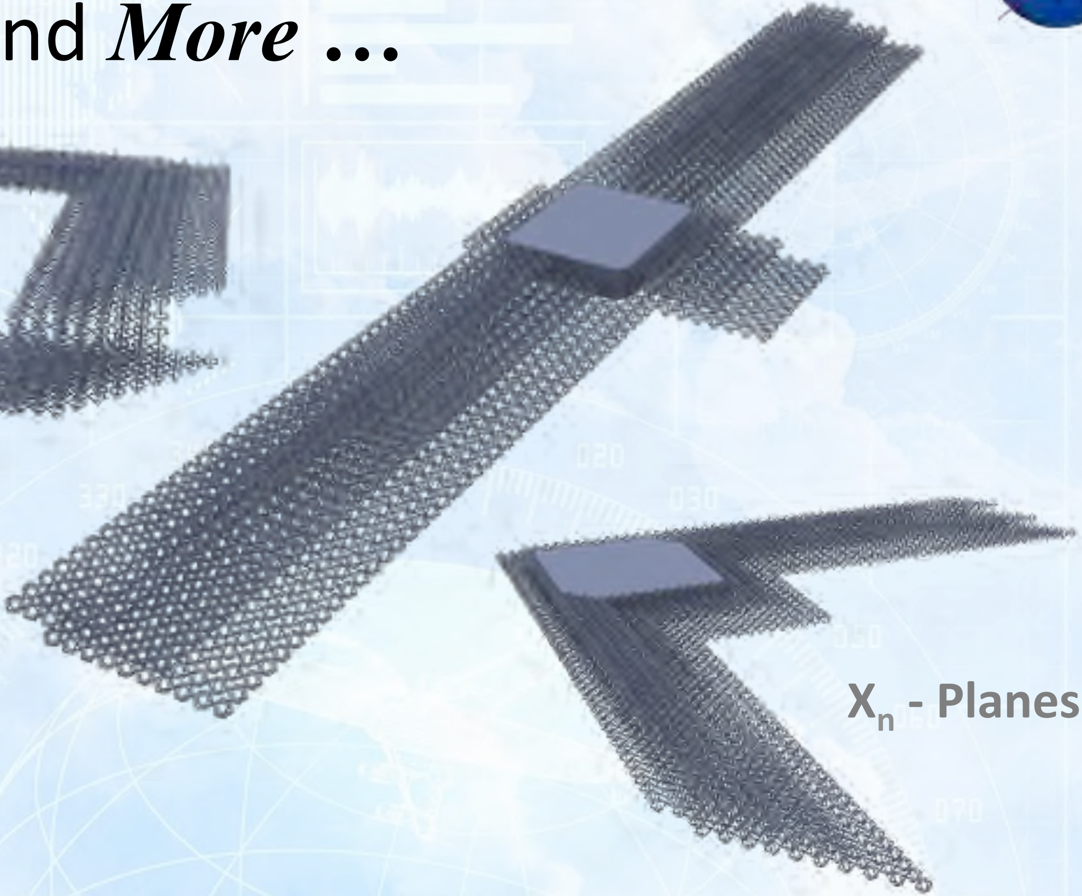
- ✓ Distributed IMUs
- ✓ String Potentiometers
- ✓ 360-deg video cam

Next Steps: Development of MADCAT v1 and ***More*** …



MADCAT v1





X_n - Planes

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MADCAT

Thank You!

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